3rd Integrated CNS Technologies Conference & Workshop Annapolis, MD

# The Aeronautical Data Link:

## Decision Framework for Architectural Analysis

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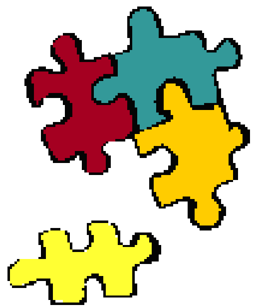
## Objective

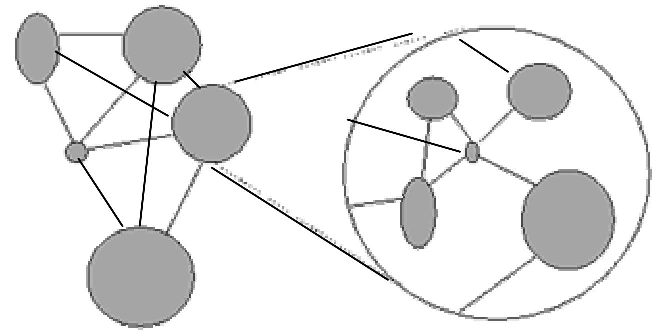
The future CNS/ATM system will rely on global satellite navigation, and ground-based and satellite based communications via Multi-Protocol Networks (e.g., combined Aeronautical Telecommunications Network (ATN)/Internet Protocol (IP)) to bring about needed improvements in efficiency and safety of operations to meet increasing levels of air traffic.  This presentation will discuss specific approaches for mapping and transitioning between the levels of a practical multi-level decision framework that completely describes optimal data link architecture configuration and behavior.

## Agenda

- Background
  - Variability of Data Link Information Networks
  - The Data Link Decision Framework
- Application of Data Link Decision Framework
  - SATS HVO Example: Goal #1 (Instantiating Operational Concepts)
  - SATS HVO Example: Goal #2 (Required Data Link Capabilities)
  - SATS HVO Example: Goal #3 (Required System Performance)
  - SATS HVO Example: Goal #4 (Required Technology Performance)
- Conclusions

# Variability of Data Link Information Infrastructures





## *Reductionism*

***Reductionism*** is an approach to building and optimizing systems out of the description of subsystems that a system is composed of and ignoring the relationships between them.

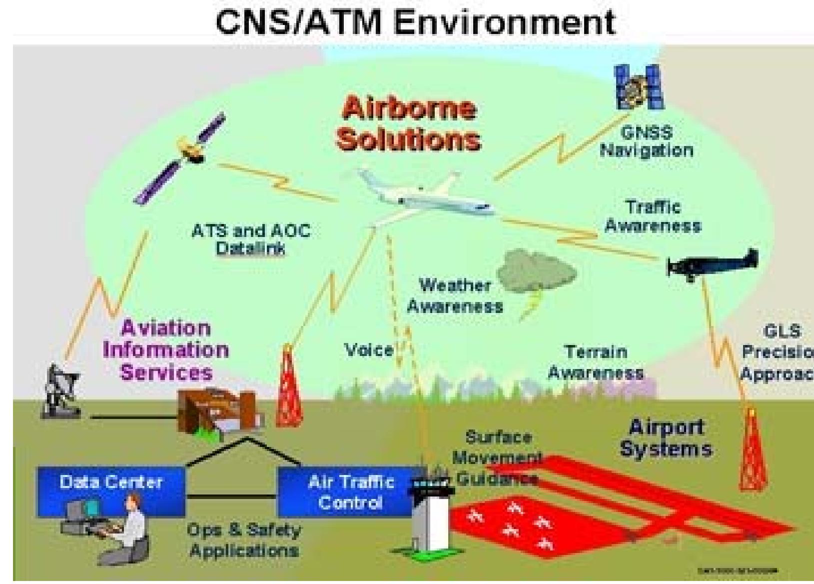
- locally optimized architecture designs
- minimal to no interactions between subsystems
- impedes system-wide optimization

## *Complexity*

***Complex systems*** is an approach that studies how parts of a system give rise to the collective behaviors of the system and how the system interacts with its environment.

- unified information infrastructures
- globally optimal decision-making
- increased complexity due to interactions between highly coupled dissimilar systems

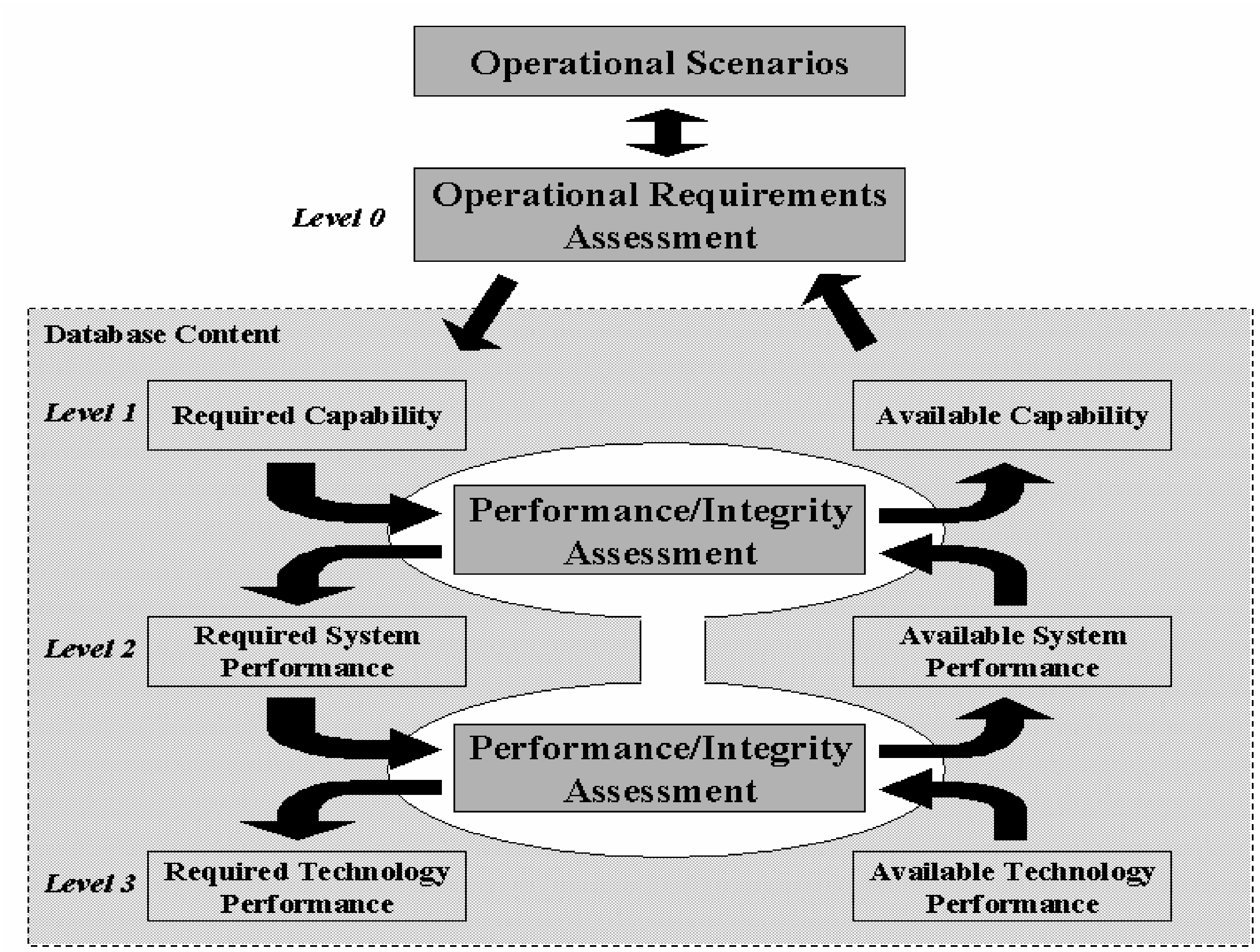
## Architecture Analysis Approach




The ATN is the complex, global network that will integrate CNS/ATM components. It's behavior is a response to both discrete-time events (digital flight control computers and clocked data links) and continuous-time events (flight operations). Designing and configuring data link systems that are ATN/IP compliant involves the simultaneous satisfaction of conflicting criteria related to operations requirements, system performance, technology capabilities, spectrum issues, data link services, etc.

We propose the use of a multi-level decision framework that determines optimal system-wide data link architecture configuration and behavior. We demonstrate its feasibility by applying it to a SATS High Volume Operations (HVO) concept and explain the use of models and tools for transitioning between the levels.

# Data Link Decision Framework




## Decision Framework

- The partitioned multi-level structure allows users with vastly different goals to operate in a consistent decision methodology
- The left-side permits top-down analysis ***(required),*** the right side permits bottom-up analysis ***(available)***
- Allows the use of external modeling tools/techniques to guide decisions
- Data for each level is clustered in a multi-dimensional database
- **Level 0** > operational scenarios and functions ***(conceptual level)***
- **Level 1** > informational capabilities ***(capability level)***
- **Level 2** > data link services ***(system level)***
- **Level 3** > technical requirements & DL technologies ***(technology level)***
- Transition Tables convert/map information between Levels

# Data Link Taxonomy

## Information Organization

### Operation Scenario

Highly Interactive, Information Centric Airspace Operations

- Enroute (non-remote)
- Terminal Area & Surface Ops
- Enroute (oceanic/remote)

### Operational Functions Capability

- Navigation Performance
- Traffic Conflict Avoidance
- Obstacle/Weather Avoidance
- Relevant Flight Rules

### Information Capability

- Timeliness
- Operational Function Mapping
- Integrity
- Capacity
- Accuracy

### Data Link Service

- Air Traffic Mgm't Services Group
- Navigation Group
- Surveillance Group
- Flight Information Services Group
- Airline Operational & Administrative Comm. Group

### Technology Requirements

- Network Interoperability Requirements
- Performance Requirements
- Equipage Requirements

### Data Link Technologies

- VDL Mode 1
- VDL Mode 2
- VDL Mode 3
- VDL Mode 4
- Mode S
- Experi-mental
- High Frequency
- SATCOM

## Application of Data Link Decision Framework

The Small Aircraft Transportation System **(SATS)** under development by NASA, FAA, and other authorities has developed a Concept of Operations **(CONOPS)** document that defines the 2010 SATS consisting of:

- Higher Volume Operation ***(HVO)*** at Non-Towered/Non-Radar Airports,
- Lower Landing Minimums and Minimally Equipped Landing Facilities,
- Increased Single-Pilot Crew Safety and Mission Reliability,
- Systems for Integrated Fleet Operations.

The SATS CONOPS ***HVO*** Operation Concept will be used as an Example…

The Example HVO Decision **Goals**: ***(a Level 0 to Level 3 Top-Down process)***

**Goal 1.** Instantiate the Operational Concepts (Level 0),

**Goal 2.** Determine the capabilities required to support the operations (Level 1),

**Goal 3.** Determine the system performance requirements for a DL service (Level 2),

**Goal 4.** Determine the minimum technology performance requirements (Level 3).

# Format of Transition Tables

The Transition Table for each Level maps the ***Performance Parameters (P)*** of the ***Enabling Functions (F)*** to the ***Requirements (R)*** as follows:

Requirements $<R_L>$

| Enabling Functions $<F_L>$ | Performance Parameters $<P_L>$ |
|---|---|

mapping: $<R_L> \leftarrow <F_L(P_L)>$

e.g., ➔

Data Link Service
Capability Requirements - Level 1

| Information Requirement | Required Data Link Capability | | | | | |
|---|---|---|---|---|---|---|
| | Aid to Visual Acq. | Taxi | Approach | Leg 2 | Leg 1 | Transition to Terminal Area |
| Timeliness | | | | | | |
| • Initial Acq(nm) | 10 | 5 | 10 | 20 | 40 | 90 |
| • Alert Time | N/A | 10 sec. | 34 sec. | 2.6 min. | 2.6 min. | 5 min. |
| Integrity | | | | | | |
| • Availability | 95% | 99.9% | 99.9% | 99.9% | 95% | 95% |
| • Nav. Integrity | 95% | 99.9% | 99.9% | 99.9% | 95% | 95% |
| Accuracy | | | | | | |
| • RNP Pos. (nm) | n/a | GPS w/ SA | GPS w/ SA | 4 | No Containment Overlap | No Containment Overlap |
| • RVP Vel. (m/s) | n/a | .06 | .06 | .06 | | |
| Information Elements (Msg's) (#blocks/#symbols) | | | | | | |
| • Current State | 7/28 | 7/28 | 7/28 | 7/28 | 7/28 | 7/28 |
| • Intended State | 7/28 | 7/28 | 7/28 | 7/28 | 7/28 | 7/28 |
| • Capability | | 6/9 | 6/9 | 6/9 | 6/9 | 6/9 |

Data link Information is transitioned (mapped) to the next level according to the relation ➔

$$<R_L> \leftarrow <F_{L-1}(P_{L-1})>$$

where

$L$ = Levels 1 to M-1, M=4

$R_L$ = Requirements

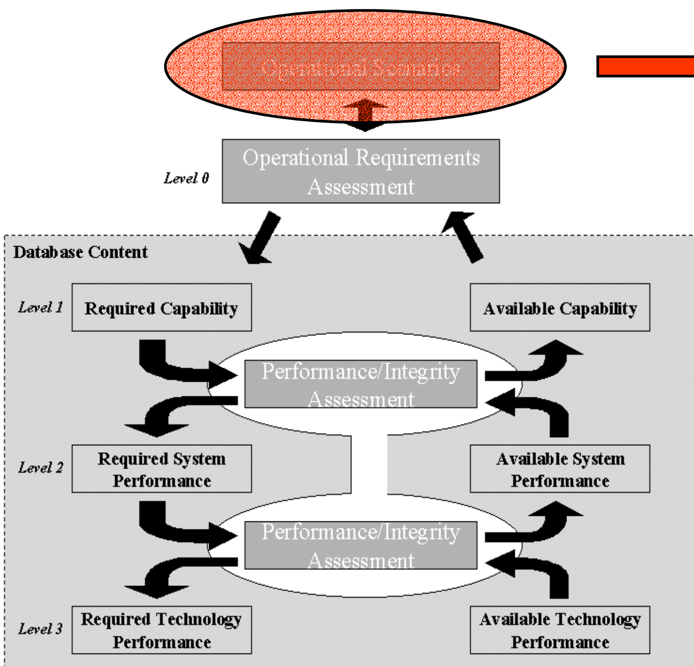
$F_L$ = Enabling Functions

$P_L$ = Performance Parameters

i.e., the ***R***equirements of the current Level represent the ***F*** and ***P*** of the previous Level

# The Aeronautical Data Link: Decision Framework

## SATS HVO Example: Goal #1 (Operational Concepts)




**2010 SATS CONOPS (HVO)**

- Horizontal Labels = required operations
- Vertical Labels = functions necessary to complete the operations
- Matrix Elements = performance parameters required to execute the functions

### Supported Operations

**HVO Operational Requirements - Level 0**

| Operational Function | Required Operation: File HVO/IFR Flight Plan | Departure/ Arrival Request | Departure/ Arrival Assignment | Takeoff/ Approach | Transition To/From ATC | | |
|---|---|---|---|---|---|---|---|
| Traffic Density | | # Aircraft | # Aircraft | | | | |
| Op. Time Window | | | | | | | |
| Requested Nav. Parameters<br>▪ Dep/Arr Fix<br>▪ Dep./Arr. Time<br>▪ A/C State | | Req'st Signa<br>Dest. Pos.<br>Time<br>Pos./Vel. | | | | | |
| Assigned Nav. Parameters<br>▪ Sequence<br>▪ Dep./Arr. Time<br>▪ Velocity | | | Queue Pos.<br>Time<br>1st Leg Vel. | | | | |
| Self-Sequencing | | | | Traj. Intent | Traj. Intent | | |
| Self-Separation | | | | Req'd Nav. Perf. Acc'y. (nm, kts) | | | |
| Release To/From ATC | | | | | Sig. Acq. Range | | |

# The Aeronautical Data Link: Decision Framework

## SATS HVO Example: Goal #1 (Instantiated)

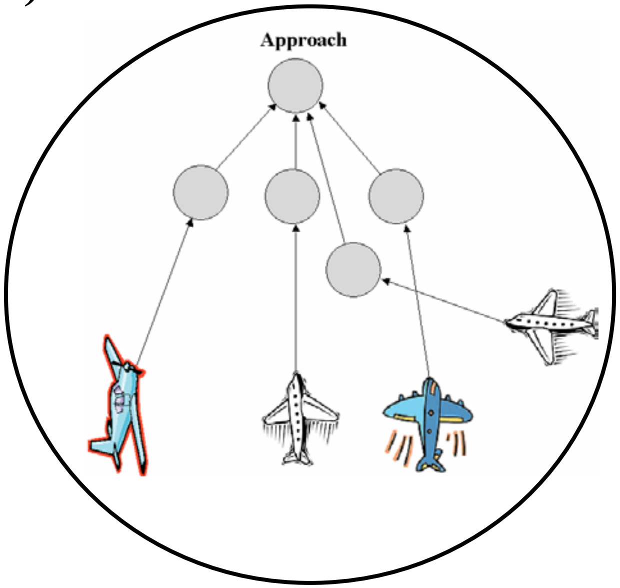
***4 Aircraft Approach Scenario***

***Goal Programming model for HVO :***

$$\min Z = \sum_i \sum_j \left( d_{ij}^- + d_{ij}^+ \right)$$

***subject to:***

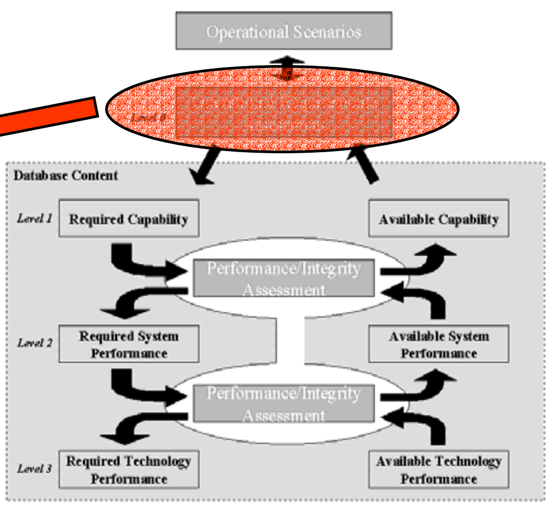
$$X_{ij-1} + \sum_k \Big\{ \frac{1}{k} \sec \theta_{ij} \left( t_{ij} \pm (i-1)(\delta t_{ij}) \right) V_{ijk-1} + \frac{1}{k} \sec \theta_{ij} \left( t_{ij} \pm (i-1)(\delta t_{ij}) \right) V_{ijk} \Big\} + d_{ij}^- - d_{ij}^+ = X_{ij}$$




### Estimation of Level 0 Performance Parameters

Information Performance Requirements - Level 0

| Performance Parameter | Operational Function | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Operation Time Window | Requested Navigation Parameters | | | | Assigned Navigation Parameters | | | | Self Sequencing | | | | Self Separation | | | | Release To/From ATC |
| Aircraft # | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | |
| Initial Velocity (kts) | 15 min | 120 | 120 | 120 | 120 | | | | | | | | | | | | | |
| Leg 1 Dist. (nm) | | 25 | 24 | 25 | 26 | | | | | | | | | | | | | |
| Leg 1 Time (min) | 15 min | 12.5 | 11.9 | 12.5 | 13 | 12.5 | 11.9 | 12.5 | 13 | | | | | | | | | |
| Leg 1 End Vel (kts) | 15 min | | | | | 120 | 120 | 120 | 120 | | | | | | | | | 30 nm |
| Leg 1 Vel Adj (kts) | 15 min | | | | | | | | | 0 | 0 | 0 | 0 | | | | | |
| Leg 1 End Vel (kts) | 15 min | | | | | | | | | 120 | 120 | 120 | 120 | | | | | |
| Leg 1 EPU (nm) | 15 min | | | | | | | | | | | | | 0.0 | 0.0 | 0.0 | 0.0 | |
| Leg 1 EVU (m/s) | 15 min | | | | | | | | | | | | | 0.0 | 0.0 | 0.0 | 0.0 | |
| Leg 2 Dist. (nm) | | 12.5 | 10 | 12.5 | 15.2 | | | | | | | | | | | | | |
| Leg 2 Rel. Hdg. (°) | | 22.2 | 0.0 | -22 | 31.3 | | | | | | | | | | | | | |
| Leg 2 Time (min) | 15 min | 6.25 | 5 | 6.25 | 7.6 | 6.25 | 6.2 | 9.34 | 13.1 | | | | | | | | | |
| Leg 2 Velocity (kts) | 15 min | | | | | 80.6 | 80.6 | 80.6 | 80.6 | | | | | | | | | |
| Approach Vel. (kts) | 15 min | | | | | 80 | 80 | 80 | 80 | | | | | | | | | |
| App Vel Adj (kts) | 15 min | | | | | | | | | .12 | 0.08 | 0 | -0.1 | | | | | |
| Approach Vel. (kts) | | | | | | | | | | 80.1 | 80.1 | 80 | 79.9 | | | | | |
| Leg 2 EPU (nm) | 15 min | | | | | | | | | | | | | 3.5 | 1.7 | 0 | 2.3 | |
| Leg 2 EVU (m/s) | 15 min | | | | | | | | | | | | | .06 | .04 | 0 | .05 | |

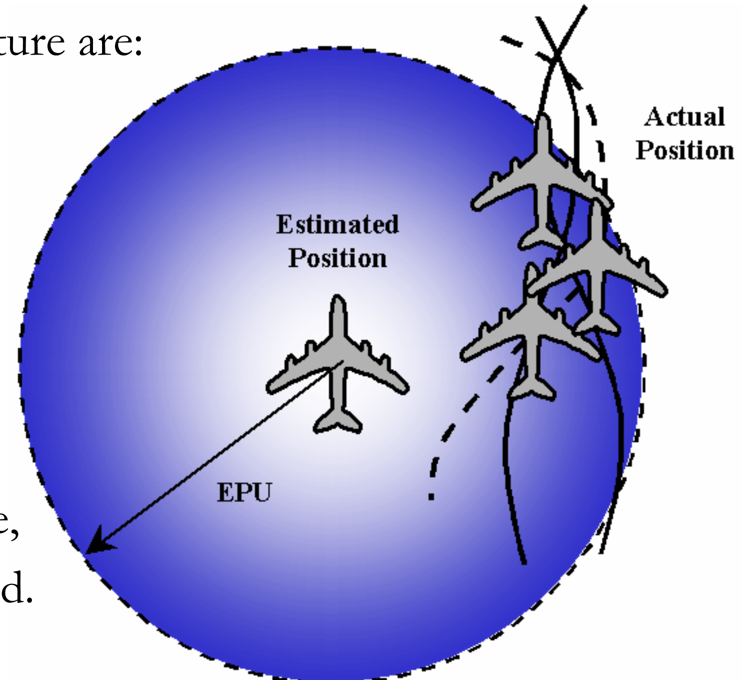


# SATS HVO Example: Goal #2 (Required Capabilities)

The objective at this point is to develop a model that maps the operational functions (Level 0) to a set of required capabilities.

The ***capabilities required*** by the informational infrastructure are:

- **navigational accuracy** *(a function of position and velocity)*
- **timeliness** *(a function of initial acquisition and alert time)*
- **overall integrity** *(a function of availability and navigational integrity)*




In order to characterize navigational errors in the airspace and to provide bounds on aircraft separation and assurance, the **Estimate of Position Uncertainty (EPU)** will be used.

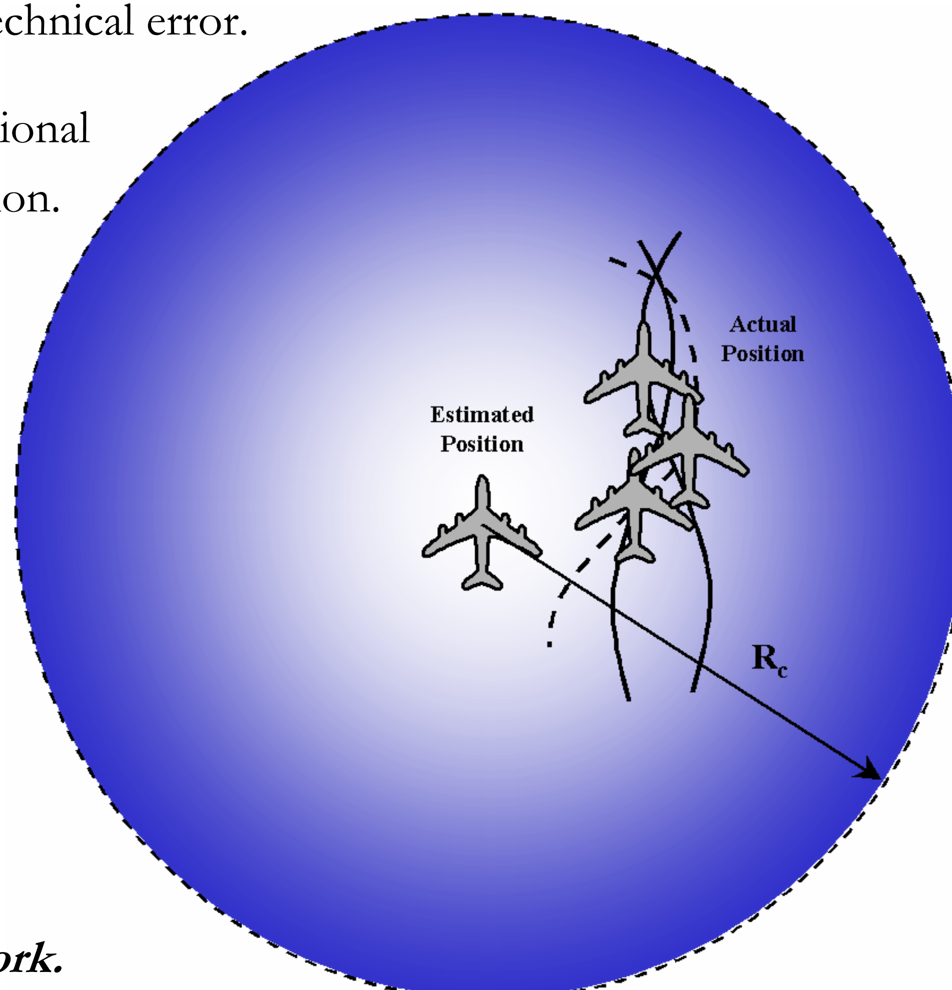
***EPU*** = the radius of a circle centered on an estimated position such that the probability that the actual position lies in the circle is 95%

# Required Navigational Performance (RNP)

**RNP** is a measure of the navigational performance accuracy required of the population of aircraft operating within a defined airspace. It is comprised of navigational error, computational error, display error, course error, and flight technical error.

This example will only use horizontal navigational error to provide measures on aircraft separation. The errors will be characterized by: **EPU**, **EVU**, and the Containment Radius (**$R_c$**)

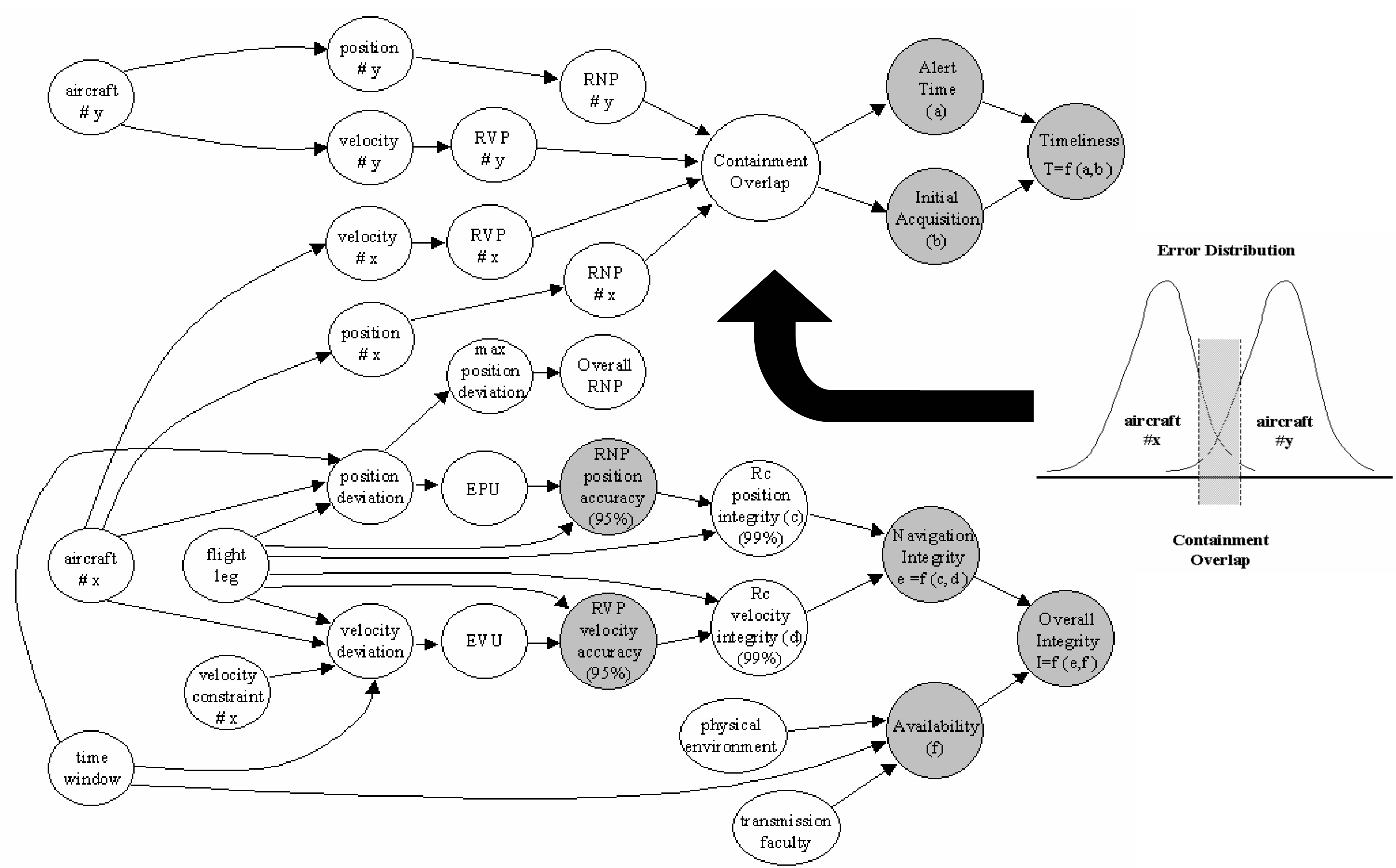
**$R_c$** = the radius of a circle centered on an estimated position such that the probability that the actual position lies in the circle is 99.999%




*Given these constraints, we were able to develop a model that mapped the Level 0 operational functions to the set of required capabilities using a tool called a* ***Bayesian Network.***

# The Aeronautical Data Link: Decision Framework

## SATS HVO Example: Goal #2 (Bayesian Network Model)



# SATS HVO Example: Goal #2 (Capabilities Computed)

## Level 0 Matrix

**Estimation of Level 0 Performance Parameters**

Information Performance Requirements - Level 0

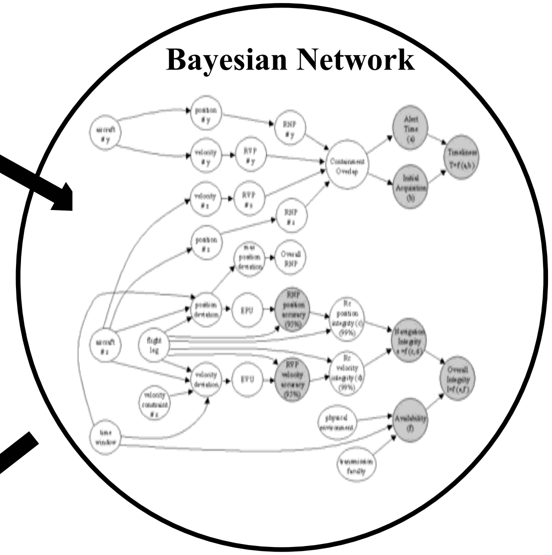
| Performance Parameter | Operation Time Window | Requested Navigation Parameters | | | | Assigned Navigation Parameters | | | | Self Sequencing | | | | Self Separation | | | | Release To/From ATC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aircraft # | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | |
| Initial Velocity (kts) | 15 min | 120 | 120 | 120 | 120 | | | | | | | | | | | | | |
| Leg 1 Dist. (nm) | | 25 | 24 | 25 | 26 | | | | | | | | | | | | | |
| Leg 1 Time (min) | 15 min | 12.5 | 11.9 | 12.5 | 13 | 12.5 | 11.9 | 12.5 | 13 | | | | | | | | | |
| Leg 1 End Vel (kts) | 15 min | | | | | 120 | 120 | 120 | 120 | | | | | | | | | 90 nm |
| Leg 1 Vel Adj (kts) | 15 min | | | | | | | | | 0 | 0 | 0 | 0 | | | | | |
| Leg 1 End Vel (kts) | 15 min | | | | | | | | | 120 | 120 | 120 | 120 | | | | | |
| Leg 1 EPU (nm) | 15 min | | | | | | | | | | | | | 0.0 | 0.0 | 0.0 | 0.0 | |
| Leg 1 EVU (m/s) | 15 min | | | | | | | | | | | | | 0.0 | 0.0 | 0.0 | 0.0 | |
| Leg 2 Dist. (nm) | | 12.5 | 10 | 12.5 | 15.2 | | | | | | | | | | | | | |
| Leg 2 Rel. Hdg. (°) | | 22.2 | 0.0 | -22 | 31.3 | | | | | | | | | | | | | |
| Leg 2 Time (min) | 15 min | 6.25 | 5 | 6.25 | 7.6 | 6.25 | 6.2 | 9.34 | 13.1 | | | | | | | | | |
| Leg 2 Velocity (kts) | 15 min | | | | | 80.6 | 80.6 | 80.6 | 80.6 | | | | | | | | | |
| Approach Vel. (kts) | 15 min | | | | | 80 | 80 | 80 | 80 | | | | | | | | | |
| App Vel Adj (kts) | 15 min | | | | | | | | | .12 | 0.08 | 0 | -0.1 | | | | | |
| Approach Vel. (kts) | | | | | | | | | | 80.1 | 80.1 | 80 | 79.9 | | | | | |
| Leg 2 EPU (nm) | 15 min | | | | | | | | | | | | | 3.5 | 1.7 | 0 | 2.3 | |
| Leg 2 EVU (m/s) | 15 min | | | | | | | | | | | | | .06 | .04 | 0 | .05 | |

***Goal Programming model for HVO :***

$$\min Z = \sum_i \sum_j \left( d_{ij}^- + d_{ij}^+ \right)$$

***subject to:***

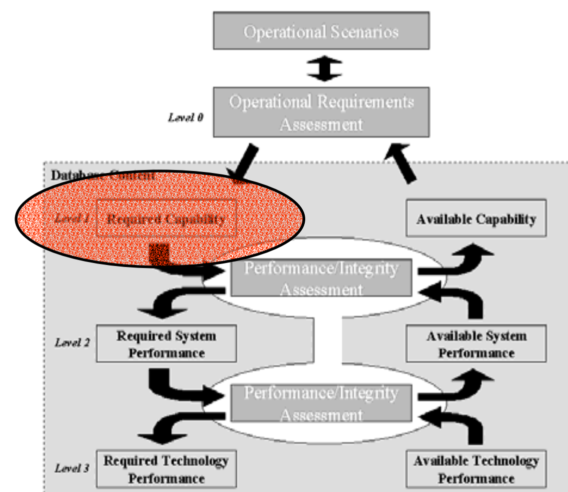
$$X_{ij-1} + \sum_k \left\{ \frac{1}{k} \sec \theta_{ij} \left( t_{ij} \pm (i-1)(\delta t_{ij}) \right) V_{ijk-1} + \frac{1}{k} \sec \theta_{ij} \left( t_{ij} \pm (i-1)(\delta t_{ij}) \right) V_{ijk} \right\} + d_{ij}^- - d_{ij}^+ = X_{ij}$$




## Data Link Service

Capability Requirements - Level 1

| Information Requirement | Required Data Link Capability: Aid to Visual Acq. | Taxi | Approach | Leg 2 | Leg 1 | Transition to Terminal Area |
|---|---|---|---|---|---|---|
| **Timeliness** | | | | | | |
| • Initial Acq(nm) | 10 | 5 | 10 | 20 | 40 | 90 |
| • Alert Time | N/A | 10 sec. | 34 sec. | 2.6 min. | 2.6 min. | 5 min. |
| **Integrity** | | | | | | |
| • Availability | 95% | 99.9% | 99.9% | 99.9% | 95% | 95% |
| • Nav. Integrity | 95% | 99.9% | 99.9% | 99.9% | 95% | 95% |
| **Accuracy** | | | | | | |
| • RNP Pos. (nm) | n/a | GPS w/ SA | GPS w/ SA | 4 | No Containment Overlap | No Containment Overlap |
| • RVP Vel. (m/s) | n/a | .06 | .06 | .06 | | |
| **Information Elements (Msg's) (#blocks/#symbols)** | | | | | | |
| • Current State | 7/28 | 7/28 | 7/28 | 7/28 | 7/28 | 7/28 |
| • Intended State | 7/28 | 7/28 | 7/28 | 7/28 | 7/28 | 7/28 |
| • Capability | | 6/9 | 6/9 | 6/9 | 6/9 | 6/9 |



# The Aeronautical Data Link: Decision Framework

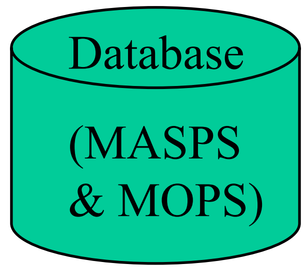
## SATS HVO Example: Goal #3 (Required System Performance)

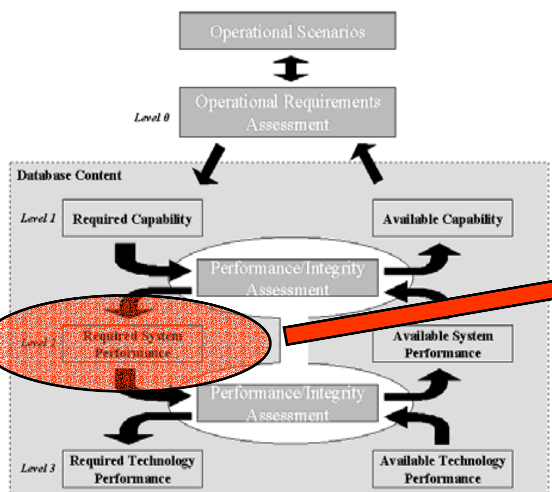
- L1 maps DL capabilities to suitable DL services
- Select suitable DL service from Data Base
- Data Base returns Performance values for the Information Elements of the DL service that meets the required DL capabilities
- ***ADS-B DL service** is suitable for SATS HVO*

### Level 1 Matrix

Data Link Service
Capability Requirements - Level 1

| Information Requirement | Required Data Link Capability: Aid to Visual Acq | Taxi | Approach | Leg 2 | Leg 1 | Transition t Terminal Ar |
|---|---|---|---|---|---|---|
| Timeliness | | | | | | |
| • Initial Acq(nm) | 10 | 5 | 10 | 20 | 40 | 90 |
| • Alert Time | N/A | 10 sec. | 34 sec. | 2.6 min. | 2.6 min. | 5 min. |
| Integrity | | | | | | |
| • Availability | 95% | 99.9% | 99.9% | 99.9% | 95% | 95% |
| • Nav. Integrity | 95% | 99.9% | 99.9% | 99.9% | 95% | 95% |
| Accuracy | | | | | | |
| • RNP Pos. (nm) | n/a | GPS w/ SA | GPS w/ SA | 4 | No Contain- | No Contain- |
| • RVP Vel. (m/s) | n/a | .06 | .06 | .06 | ment Overlap | ment Overlap |
| Information Elements (Msg's) (#blocks/#symbols) | | | | | | |
| • Current State | 7/28 | 7/28 | 7/28 | 7/28 | 7/28 | 7/28 |
| • Intended State | 7/28 | 7/28 | 7/28 | 7/28 | 7/28 | 7/28 |
| • Capability | | 6/9 | 6/9 | 6/9 | 6/9 | 6/9 |




### Data Link Application

Performance Requirements - Level 2

| Information Element | System Performance Requirements – A2 Equipage: Aid to Visual Acq. | Airport Surface | Simultaneous Approach | Conflict Avoidance | Separation Assurance & Sequencing | Flight Path Deconfliction Planning |
|---|---|---|---|---|---|---|
| | Enroute-R Enroute-NR Terminal | Enroute-R Enroute-NR Terminal | Enroute-R Enroute-NR Terminal | Enroute-R Enroute-NR Terminal | Enroute-R Enroute-NR Terminal | Enroute-R Enroute-NR Terminal |
| State Vector | | | | | | |
| Accuracy (m-m/s) | 200-n/a | 2.5-0.3 | 20-0.3 | 20/50-.6/.75 | 20/50-.3/.75 | 200-5 |
| Update Rate | 3s – 5s | 1.5 s | 1.5s | 7 s | 12 s | 12 s |
| Acquisition Range | 10 nm | 5 nm | 10 nm | 20 nm | 40 nm | 90 nm |
| # Symbols | 54 | 54 | 54 | 54 | 54 | 54 |
| Mode Status | | | | | | |
| Update Rate | | | | | | |
| Acquisition Range | 10 nm | 5 nm | 10 nm | 20 nm | 40 nm | 90 nm |
| # Symbols | 47 | 47 | 47 | 47 | 47 | 47 |
| Air Ref. Velocity | | | | | | |
| Update Rate | n/a | n/a | 5 s | 7 s | 12 s | 12 s |
| Acquisition Range | n/a | n/a | n/a | 20 nm | 40 nm | 90 nm |
| # Symbols | n/a | n/a | n/a | 18 | 18 | 18 |
| Target State/Chg. | | | | | | |
| Update Rate | n/a | n/a | n/a | 12 s | 12 s | n/a |
| Acquisition Range | n/a | n/a | n/a | 20 nm | 40 nm | 90 nm |
| # Symbols | n/a | n/a | n/a | 84 | 84 | 84 |

# The Aeronautical Data Link: Decision Framework

## SATS HVO Example: Goal #4 (Required Technology Performance)

### Level 2 Matrix

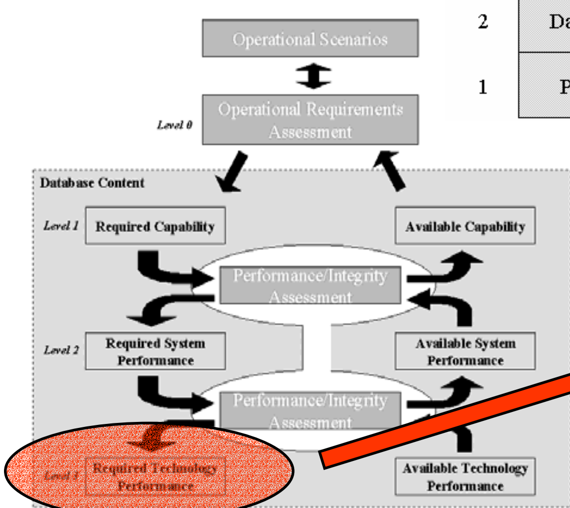
**Data Link Application**
Performance Requirements - Level 2

| Information Element | System Performance Requirements – A2 Equipage | | | | | |
|---|---|---|---|---|---|---|
| | Aid to Visual Acq. | Airport Surface | Simultaneous Approach | Conflict Avoidance | Separation Assurance & Sequencing | Flight Path Deconfliction Planning |
| | Enroute-R Enroute-NR Terminal | Enroute-R Enroute-NR Terminal | Enroute-R Enroute-NR Terminal | Enroute-R Enroute-NR Terminal | Enroute-R Enroute-NR Terminal | Enroute-R Enroute-NR Terminal |
| State Vector | | | | | | |
| Accuracy (m-m/s) | 200-n/a | 2.5-0.3 | 20-0.3 | 20/50-.6/.75 | 20/50-.3/.75 | 200-5 |
| Update Rate | 3s – 5s | 1.5 s | 1.5s | 7 s | 12 s | 12 s |
| Acquisition Range | 10 nm | 5 nm | 10 nm | 20 nm | 40 nm | 90 nm |
| # Symbols | 54 | 54 | 54 | 54 | 54 | 54 |
| Mode Status | | | | | | |
| Update Rate | | | | | | |
| Acquisition Range | 10 nm | 5 nm | 10 nm | 20 nm | 40 nm | 90 nm |
| # Symbols | 47 | 47 | 47 | 47 | 47 | 47 |
| Air Ref. Velocity | | | | | | |
| Update Rate | n/a | n/a | 5 s | 7 s | 12 s | 12 s |
| Acquisition Range | n/a | n/a | n/a | 20 nm | 40 nm | 90 nm |
| # Symbols | n/a | n/a | n/a | 18 | 18 | 18 |
| Target State/Chg. | | | | | | |
| Update Rate | n/a | n/a | n/a | 12 s | 12 s | n/a |
| Acquisition Range | n/a | n/a | n/a | 20 nm | 40 nm | 90 nm |
| # Symbols | n/a | n/a | n/a | 84 | 84 | 84 |

### Shannon's Information Capacity Equations

For PSK: $$R_b = .5B\log_2\left(1+\frac{E_b}{N_o}\frac{R_b}{B}\right) \quad \text{where} \quad 1+\frac{E_b}{N_o}\frac{R_b}{B} = M$$

$$P_e = erfc\left(\sqrt{\frac{E_b}{N_o}}\sin\frac{\pi}{M}\right)$$




Lower OSI Layers

| Layer | Layer Name |
|---|---|
| 3 | Network |
| 2 | Data Link |
| 1 | Physical |

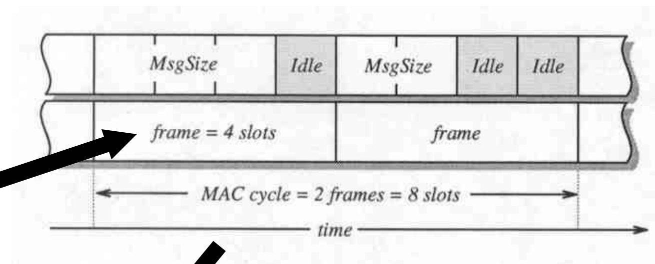
**Data Link Application**
Performance Requirements - Level 3

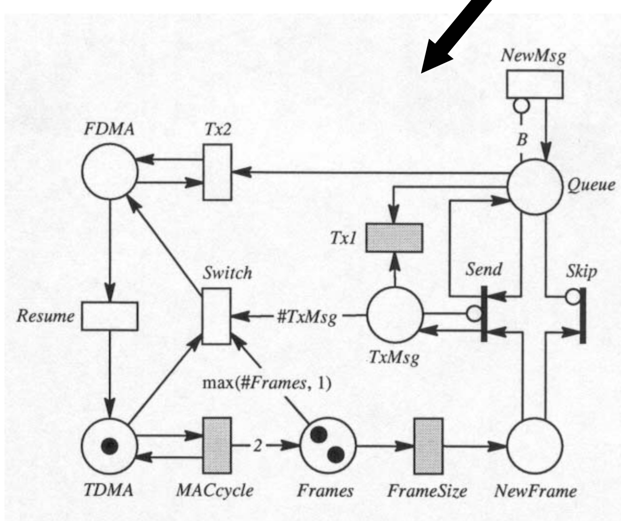
| Layer 1 Elements | Technology Performance Requirements – Physical Layer | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | # Symbols (K) [203 x #A/C] | | | | # Bits/Symbol (n) [$\log_2 M$] | | | | Symbol Duration (T) [$T_{tx}$/K] | | | | Bit Duration ($T_b$) [T/ $\log_2 M$] | | | | Probability of Symbol Error ($P_e$) [$10^{-3}$] | | | |
| | M | | | | M | | | | M | | | | M | | | | M | | | |
| | 2 | 4 | 8 | 16 | 2 | 4 | 8 | 16 | 2 | 4 | 8 | 16 | 2 | 4 | 8 | 16 | 2 | 4 | 8 | 16 |
| Bit Rate (Kbits/s) | | | | | | | | | | | | | | | | | | | | |
| • 4 aircraft | .5 | 1 | 1.5 | 2 | | | | | | | | | | | | | | | | |
| • 120 aircraft | 17 | 33 | 50 | 67 | | | | | | | | | | | | | | | | |
| BER (x $10^{-3}$) | | | | | | | | | | | | | | | | | n/a | .07 | .06 | .053 |
| $R_b$/B (bits/s/hz) | | | | | | | | | | | | | | | | | .5 | 1 | 1.5 | 2 |
| Eb/No (db) | | | | | | | | | | | | | | | | | 3.9 | 4.5 | 5.1 | 5.7 |
| B (Khz) | | | | | | | | | | | | | | | | | | | | |
| • 4 aircraft | 1 | | | | | | | | | | | | | | | | | | | |
| • 120 aircraft | 33 | | | | | | | | | | | | | | | | | | | |

# SATS HVO Example: Goal #4 (Required Technology Performance)

Lower OSI Layers

| Layer | Layer Name | Unit of Transmission |
|---|---|---|
| 3 | Network | *Packet* |
| 2 | Data Link | *Frame* |
| 1 | Physical | *Bit* |




| Measures | S1 | S2 |
|---|---|---|
| Pr{ using TDMA mode } | .7218 | .5083 |
| Pr{ using FDMA mode } | .2782 | .4917 |
| E{ utilization \| TDMA mode } | .3101 | .2997 |
| E{ utilization \| FDMA mode } | .9933 | .9008 |
| Pr{ full queue \| TDMA mode } | .0046 | .0039 |
| Pr{ full queue \| FDMA mode } | .1921 | .0300 |
| Pr{ full queue \| FDMA mode } | .0079 | .0111 |
| E{ # queued messages } | 15.87 | 9.270 |

## Conclusions

• A practical multi-level decision framework that completely describes optimal system-wide data link architecture configuration and behavior to meet multiple conflicting objectives of concurrent and different operations functions has been described. The decision analysis approach is premised on the development of a formal taxonomic classification of CNS/ATM systems, services, requirements and technologies.

• The decision framework was applied to a SATS High Volume Operations (HVO) concept application (4 Aircraft Approach Scenario) that demonstrated the feasibility of determining the minimum technology performance required to satisfy the SATS HVO Concept of Operations.

• We demonstrate the use of models (GP, etc.) and tools (Bayesian networks, etc.) for transitioning between the levels of the decision framework.